With the writer's compliments
1903 Glasgow University Library.

A CONTRIBUTION TO THE LOCALISATION OF THE MOTOR NUCLEI IN THE SPINAL CORD OF MAN

BY

ALEXANDER BRUCE,
M.A., M.D., F.R.C.P.Ed., F.R.S.Ed.,
Assistant Physician to the Edinburgh Royal Infirmary; Lecturer on Practice of Physic, Surgeons' Hall

Reprinted from *The Scottish Medical and Surgical Journal*, December 1901

A CONTRIBUTION TO THE LOCALISATION OF THE MOTOR NUCLEI IN THE SPINAL CORD OF MAN

By ALEXANDER BRUCE, M.A., M.D., F.R.C.P.Ed., F.R.S.Ed.,

Assistant Physician to the Edinburgh Royal Infirmary; Lecturer on Practice of Physic, Surgeons' Hall

It is gradually being recognised that the motor cells in the anterior cornua of the spinal cord are arranged, not in a haphazard, irregular fashion, but in certain definite groups, which are more or less constant for each segment. Up to the present time, however, those who have devoted attention to the subject are not agreed as to the distribution of these groups. This want of harmony is in part due to the difficulty, which is by no means inconsiderable, especially with regard to the lumbo-sacral region, of enumerating the segments; and in part to the want of systematic examination of the arrangement of the cell groups themselves within each segment. As the result of such an examination I have described and figured[1] the following main groups in the lumbo-sacral region:—

A. A *mesial* group, which is capable of further sub-division into an anterior and a posterior part.
B. An *antero-lateral* group.
C. A *postero-lateral* group.
D. A *post-postero-lateral* group.
E. A *central* group.

In addition to these there are other groups of cells—an intermedio-lateral, and a group internal to the antero-lateral,

---

[1] "Topographical Atlas of the Spinal Cord."

which Onuf has designated by the letter X. As it is probable from their character that these do not innervate striped muscle, they will not be further referred to in this communication, nor will a small group found in the second lumbar segment immediately lateral to the mesial group, which I have termed the anterior group.

The *mesial* group extends from the first to the fourth lumbar segment, then, except for the presence of an occasional cell, is unrepresented in the fifth lumbar, first and second sacral. It reappears in the third sacral segment and is continued to the lower limit of the fourth, where it ceases entirely (Fig. 1, *m.*).

The *antero-lateral* group appears at the second lumbar segment as a small collection of cells at the corresponding angle of the cornu. It gradually increases in size until it forms a large and important group, which, here and there, indicates a tendency to further sub-division. Throughout the first and second sacral segments it diminishes somewhat rapidly and cannot be traced below the second sacral (Fig. 1, *a. l.*).

The *postero-lateral* group ex-

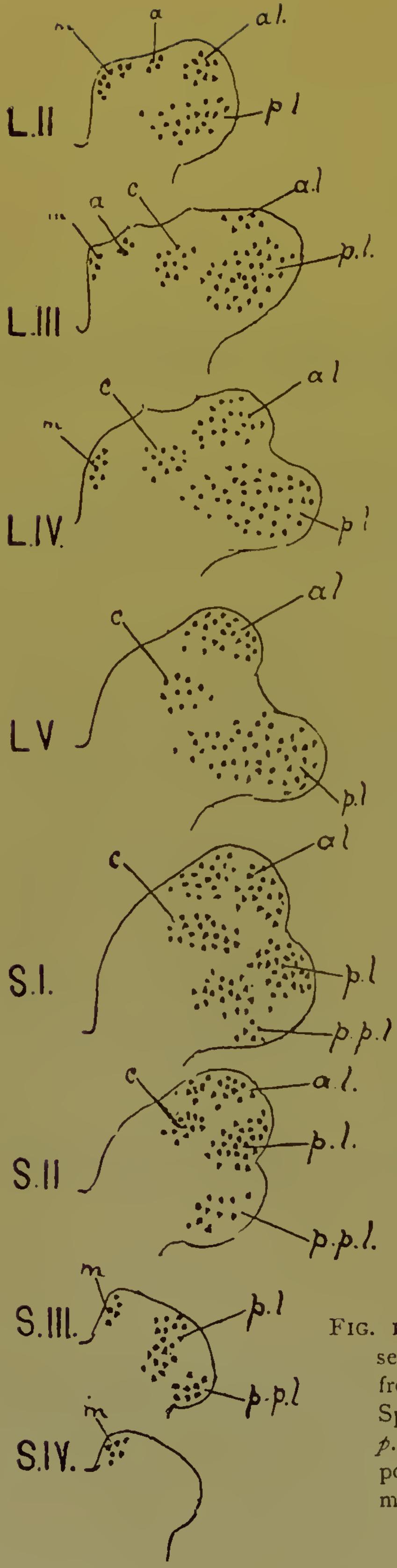


Fig. 1.—Diagram of the cell-groups in the spinal segments from L. 2 to S. 4 inclusive (reduced from the writer's "Topographical Atlas of the Spinal Cord"). *a. l.*, antero-lateral group; *p. l.*, postero-lateral group; *p. p. l.*, post-postero-lateral group; *c.*, central group; *m.*, mesial group; *a.*, anterior group.

tends from the second lumbar to the lower limit of the third sacral, and attains its maximum development at the fourth and fifth lumbar segments (Fig. 1, *p. l.*).

The *post-postero-lateral* group, as it has been termed by Onuf, is situated immediately dorsal to the preceding one, and extends from the first to the lower extremity of the third sacral segments, reaching its greatest size in the second and upper part of the third sacral (Fig. 1, *p. p. l.*).

The *central* group lies internal to and between the two main lateral groups. It extends from the second lumbar to the second sacral segments (Fig. 1, *c.*).

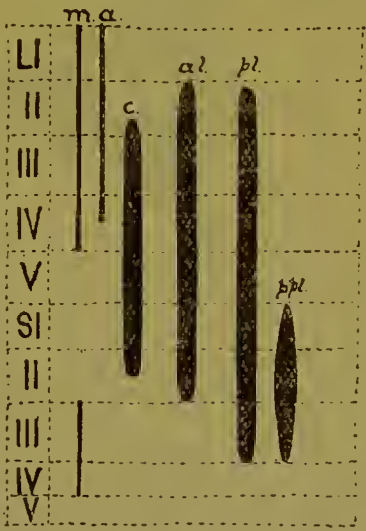


FIG. 2.—Scheme to show the longitudinal distribution of the cell-groups in the lumbo-sacral region of the cord. The letters have the same significance as in Fig. 1.

The longitudinal extent of these various groups will be more readily followed from the annexed figure (Fig. 2).

The constancy of the distribution of these groups of motor cells in the anterior cornu naturally suggests that each group has a definite function—in other words, is the spinal centre for definite muscles; but, until the discovery by Nissl of the change which occurs in the motor cells after section of the nerves which arise from them, no sufficiently exact method was available for the determination of the localisation of these centres. Nissl has shown that, when a nerve fibre is divided, the cell from which it arises undergoes certain characteristic changes, viz., the chromatic elements become gradually replaced by a finely granular, almost homogeneous material, which stains faintly with aniline dyes, and is diffused throughout the whole cell. This change affects the dendrites as well as the body of the cell, so that they stain feebly; and in consequence the cell, when viewed under low powers of the microscope at least, seems to have more or less completely lost its angular character, and to be denuded of its processes. The nucleus of the cell leaves its central position and tends to project at one side of the cell. The faintness of the staining, the rounded outline, and the eccentric position of the nucleus of the affected cell are in such decided contrast to the deeply-stained "tigroid" appearance of the normal cell, with its pointed angles, well-marked dendrites, and central nucleus, that the identification of the cells which show the *réaction à distance*, as Marinesco has termed it, is a very simple matter (Fig. 3).

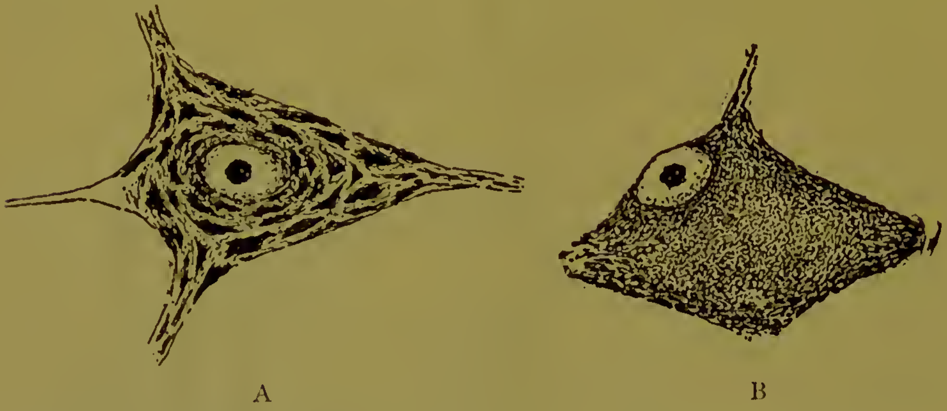
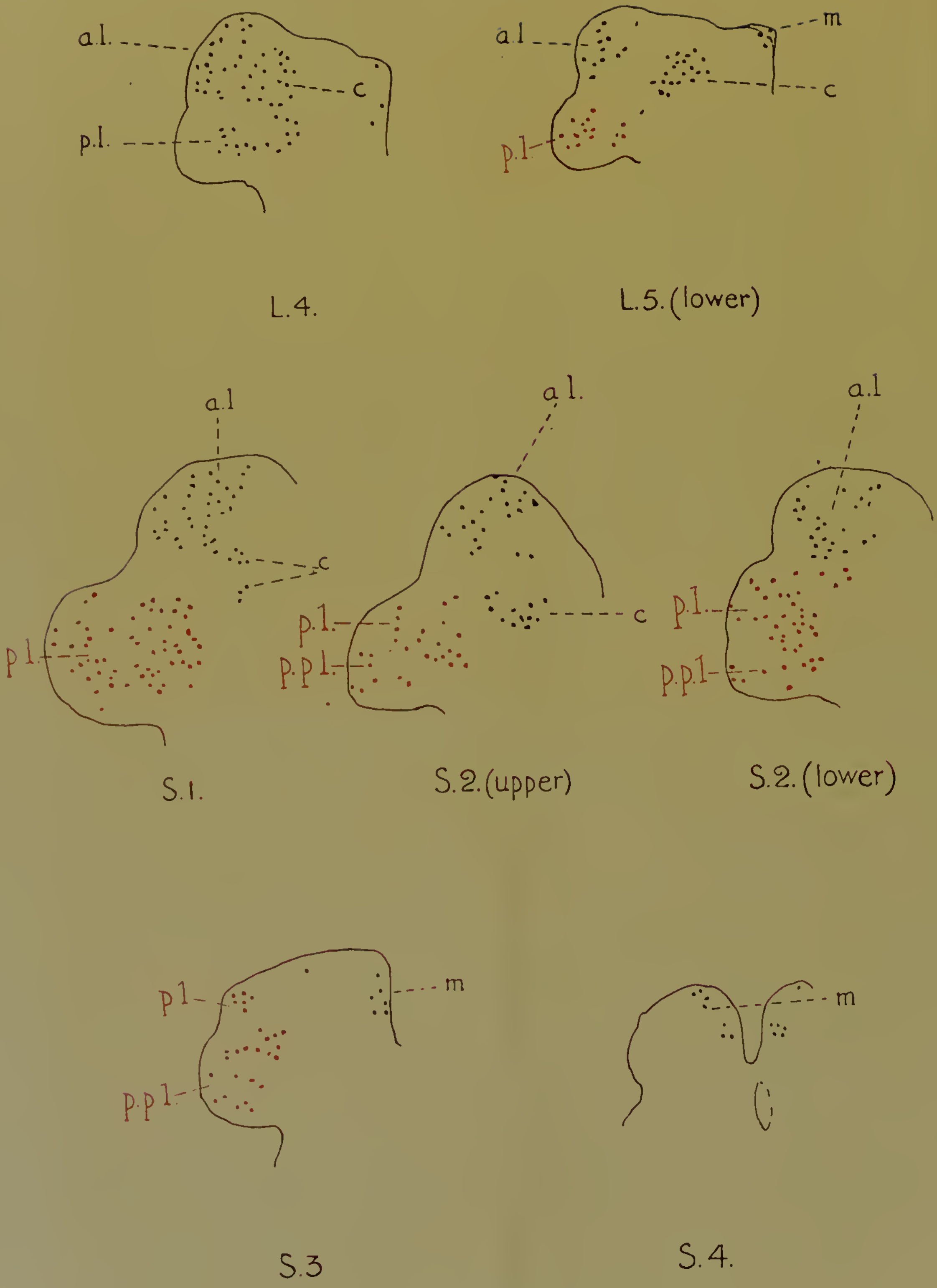


FIG. 3.—(A) Normal cell of anterior cornu. (B) Cell showing *réaction à distance* with eccentric nucleus and finely granular protoplasm.

This method of investigation may be used in two ways for the determination of the motor localisation in the cord. On the one hand, a nerve may be divided, or, what comes to the same thing, a muscle removed, and the position of the cells which show the *réaction à distance* ascertained. On the other hand, after an extensive removal of the muscles of a limb, a small group of muscles may be left attached to their motor nerves, and the position of the unaffected anterior cornual cells established. These normal cells accordingly represent the motor centres of the muscles which have not been removed.

Such experiments can easily be carried out in animals, but in the human subject observations can only be made in those comparatively rare cases where death has occurred within the necessary limits of time—not sooner than fourteen days and not later than four months after the removal of a limb or part of a limb. Two such cases I have recently had an opportunity of examining, through the kindness of my

Scot. Med. and Surg. Journal, Vol. IX., No. 6.



Normal Cells—black. Degenerate Cells—red.

Plate V.—To illustrate Dr Bruce's Paper.

friends Mr Stiles and Dr Shennan, the surgeon and pathologist, respectively, of the Royal Hospital for Sick Children. In one instance the thigh had been amputated at its lower third, *i.e.* below the level at which its muscles receive their nerve supply. In this case, therefore, the only cells to undergo the *réaction à distance* would be those which innervate the muscles of the leg and foot. In the second case, a most extensive operation was performed for tubercular disease of the hip-joint and ilium, the whole of the lower limb with the acetabulum and ilium, and (at a subsequent operation for a sinus) the spine of the ischium being removed. From a careful consideration of the steps of the operation by Mr Stiles, I am convinced that the only muscles of the lower limb which were not taken away, or were not cut off from their nerve supply, were the *psoas-iliacus* and *pectineus*, the *obturator internus*, the *pyriformis* and *gemelli.* The pudic nerve was undoubtedly injured in the removal of the ischial spine, but whether in whole or in part I am not in a position to determine with certainty.

In the first case (Plate V.), that of amputation above the knee, the motor cells in the first four lumbar segments were found to be perfectly normal (Pl. V. Fig. 1, L. 4). In *the fifth lumbar segment*, *at its upper part*, some cells in the *postero-lateral group* showed the Nissl reaction. *In the lower part of the fifth lumbar segment* (L. 5) *the whole of the postero-lateral group was affected*, *while the antero-lateral*, *central*, *and mesial groups were found to be perfectly intact. In the sacral segments the antero-lateral*, *central*, *and mesial groups were normal*, *the reaction being confined to the postero-lateral and post-postero-lateral groups* (Fig. 4, E). The maximum reaction was found at the first sacral segment (S. 1), at which level the postero-lateral group is very large, and the post-postero-lateral begins to appear. In the third sacral segment (S. 3) the whole of the lateral group of cells in the anterior cornu was affected (no doubt because, as explained in my Atlas, the antero-lateral and central groups do not extend so low down); but the whole of the cells of the mesial group in this, as also in the fourth segment (S. 4), were perfectly normal.

In this case, therefore, the *centres for the muscles of the calf and those supplying the foot were situated in that part of the* *postero-lateral column of cells which lies between the upper limit of the fifth lumbar segment and its lower termination in the third sacral segment; and also in the post-postero-lateral group throughout its entire extent.* This result is in exact agreement with that found by Van Gehuchten and De Buck (Fig. 4, B) in two cases of amputation of the lower part of the thigh, so that these columns of cells may be regarded as the centres for the muscles of the calf and those of the foot.[1]

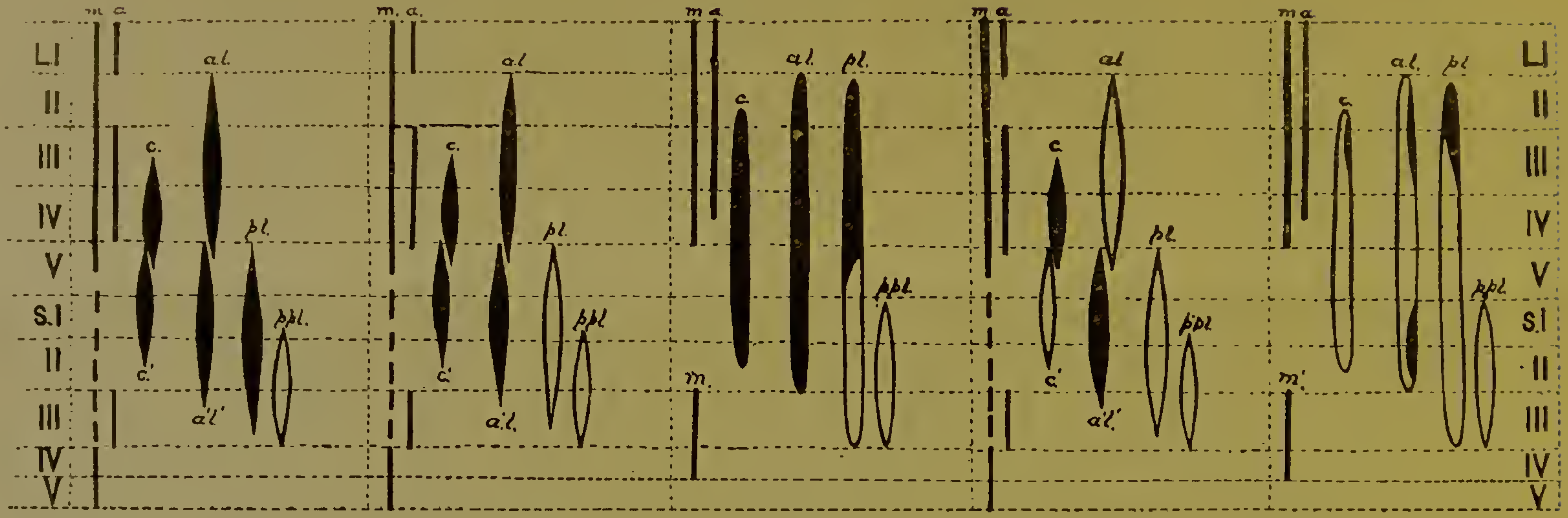
Van Gehuchten and Nelis have shown (Fig. 4, A) that in a case of *amputation at the ankle* the *réaction à distance* was limited to the *post-postero-lateral group*, or, as the former terms it, the *secondary postero-lateral group.* If this is confirmed by subsequent examination, we may regard the post-postero-lateral column from S. 1 to S. 3 as the *centre for the intrinsic muscles of the foot*, and the *postero-lateral group from the fifth lumbar to the upper part of the third sacral segment inclusive* as the *centre for the muscles of the calf, and* what may be termed *the extrinsic muscles of the foot, i.e.* those which arise from the tibia and fibula. The exact lower limit is in all probability somewhat different in different cases.

In the second case which I examined, as already said, all the muscles of the lower limb were removed, with the exception of the psoas-iliacus, pectineus, the obturator internus, pyriformis, and gemelli. In addition, all the muscles supplied by the pudic nerve were probably cut off from connection with their motor centres. (It is to be remembered that the nerves to the coccygeus muscle and to the posterior part of the levator and sphincter ani arise from the fourth sacral root independently of the pudic nerve.) It was to be expected, therefore, in such a case, that the only motor cells

---

[1] There is this difference between Van Gehuchten and myself, that whereas he does not trace the postero-lateral column higher than the fifth lumbar (see Fig. 4, A, B, D), in my opinion it extends to the upper limit of the second lumbar segment, and therefore that part of it which is situated in the second, third, and fourth lumbar segments must innervate muscles higher than those of the leg. According to Van Gehuchten the postero-lateral cell column, as he describes it, is entirely devoted to the innervation of the muscles below the knee. It is to be noted, however, that we are in entire agreement as to the position of these spinal leg centres, and at variance merely as to the longitudinal extent of the postero-lateral column.

FIG. 4.—Scheme to show longitudinal extent of *réaction à distance* after amputation at various levels. Healthy areas black, degenerated areas merely outlined.



A — At ankle. (Van Gehuchten and Nelis.)

B — At knee. (Van Gehuchten and De Buck.)

C — At knee. (Bruce and Stiles.)

D — At hip. (Van Gehuchten.)

E — At hip, with removal of ilium. (Bruce and Stiles.)

in the lumbo-sacral region left intact would be those for the psoas-iliacus, the obturator internus, the pyriformis and gemelli, and the coccygeus and the posterior part of the levator and sphincter ani. It was found in this case that the amount of the *réaction à distance* was much more extensive than in the first case, and that, with certain exceptions which will now be described, it affected the whole of the cell columns in the lumbo-sacral region below the first lumbar segment, which was normal.

In the upper part of the second lumbar segment (Plate VI., L. 2, upper) some cells in the posterior part of antero-lateral group were affected, while the remainder of the antero-lateral, the whole of the postero-lateral and mesial groups were normal. In the lower half of the segment (L. 2, lower) degenerated cells were found in increasing numbers in the antero-lateral and postero-lateral groups, but were still considerably outnumbered by the normal cells.

In the third lumbar segment (L. 3) normal cells were still present in both of the lateral groups, but their number rapidly diminished as the lower limit of the segment was approached, while, on the other hand, the degenerated cells became very numerous. In the central group several of the cells were normal. The mesial group was entirely normal.

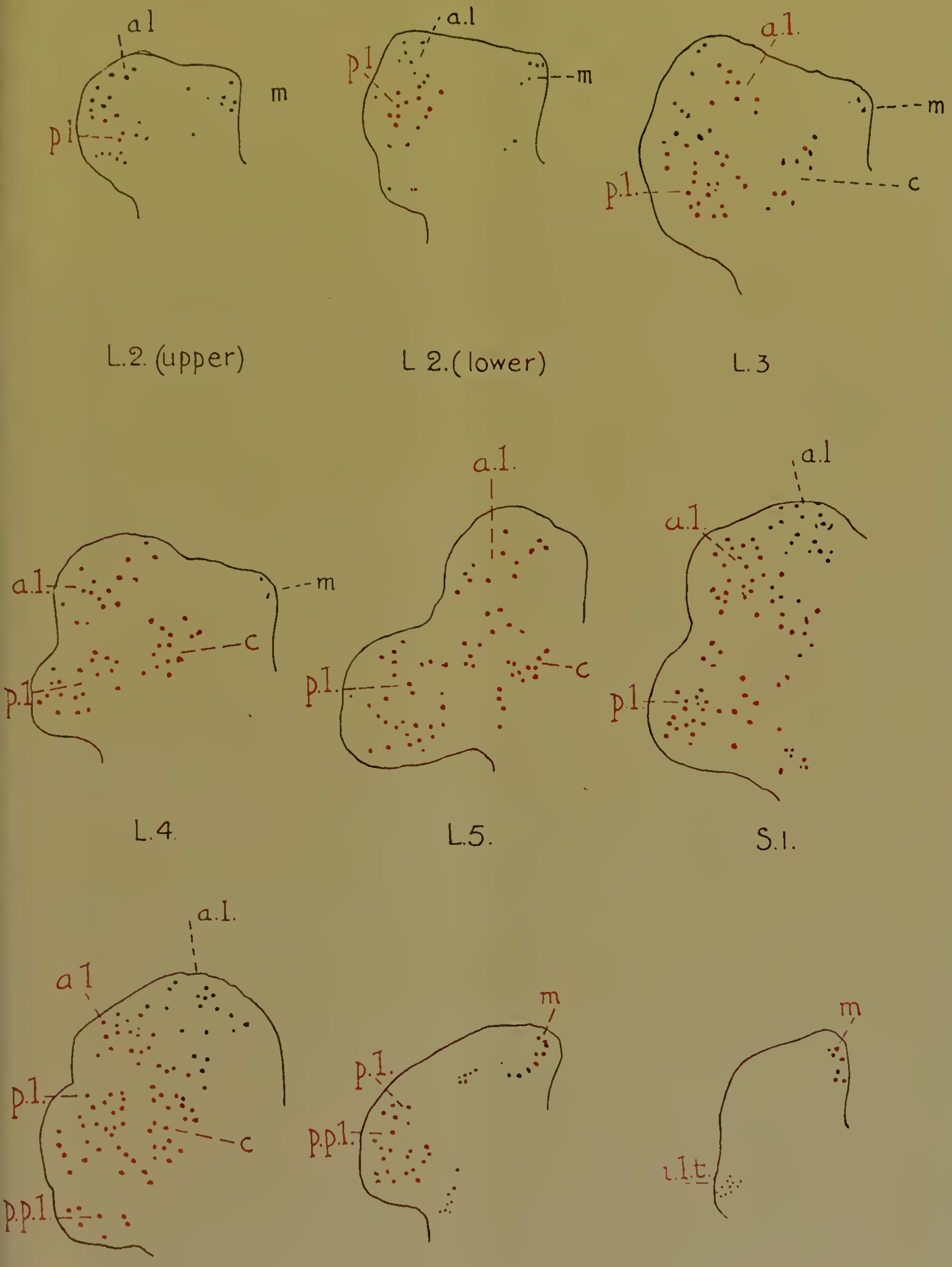
In the fourth lumbar segment (L. 4) the cells were practically all degenerated in both of the lateral groups, and in the central group. The mesial group, however, remained normal.

Of the fifth lumbar segment (L. 5) the same may be said. The lateral and central groups were degenerated; the mesial remained healthy.

In the first sacral segment (S. 1) normal cells again appeared, and gradually increased throughout the antero-lateral group until they formed a considerable proportion of its cells in the lower part of the segment. An occasional normal cell was found in the central group, but the postero-lateral was entirely degenerated.

In the second sacral segment (S. 2) a large proportion of the cells in the anterior part of the antero-lateral group remained normal, and an occasional normal cell was found in the central group. The hinder portion of the antero-

Scot. Med. and Surg. Journal, Vol. IX., No. 6



L.2. (upper) L 2. (lower) L.3

L.4. L.5. S.1.

S.2. S.3. S.4.

Normal Cells—black. Degenerate Cells—red.

PLATE VI.—TO ILLUSTRATE DR BRUCE'S PAPER.

lateral, the postero-lateral, and the post-postero-lateral groups were affected throughout.

In the third sacral segment (S. 3) there were no normal cells in the remaining portion of the lateral groups (viz., the postero-lateral and post-postero-lateral). The mesial group, which had reappeared, contained a few healthy cells, but the majority had undergone the Nissl reaction.

In the fourth sacral segment (S. 4) the mesial group, which alone persisted, was almost entirely degenerated, but the proportion of normal cells was considerably greater than in the preceding segment.[1]

To sum up the results of the examination of this second case, we have seen that there were unaltered cells in three separate positions in the lumbo-sacral cord—(1) within the second and third lumbar segment in the antero-lateral and to a less extent in the postero-lateral and central groups; (2) within the first and second sacral segments in the ventral part of the antero-lateral group; (3) within the third and fourth sacral segments in the mesial group of cells.

The distribution of the affected cells is shown in Fig. 4, E, where the portions of the antero-lateral groups remaining unaltered has been represented black. The lower mesial group (m^1) in the third and fourth sacral segments, although affected, has been left black.

We have also learned that in the removal of the limb the following muscles were left in connection with their nerve centres—(1) the psoas-iliacus and pectineus; (2) the obturator internus, pyriformis and gemelli; (3) the coccygeus and the posterior parts of the levator and sphincter ani.

The anatomical distribution of the nerves in the lumbo-sacral region indicates that the psoas-iliacus and pectineus are innervated from the second and third lumbar segments chiefly; the obturator internus is innervated from the first and second sacral segments; and the pyriformis from the second sacral. It seems therefore clear (1) that the psoas-iliacus and pectineus have their centre in the unaffected cells in the antero-lateral, postero-lateral and central groups of the second and third lumbar segments; (2) that the centres for the

---

[1] Nissl's reaction was found in the cells of the intermedio-lateral group. These, therefore, probably supply some organ through the internal pudic nerve.

obturator internus, pyriformis and gemelli are situated in the ventral portion of the antero-lateral group in the first and second sacral segments.

The mesial group in the third and fourth sacral was partly normal and partly degenerated. The explanation of this is not so clear as that of the conditions already described. It seems practically certain that the pudic nerve had been injured in its course round the spine of the ischium, and that the perineal muscles (with the exception of the posterior portions of the levator and sphincter ani, and of the coccygeus muscle which receive their nerve supply directly from the fourth sacral nerve within the pelvis), had thus become disconnected from their nerve centres. Hence the mesial group of the third and fourth sacral segments was partly affected and partly normal—a double proof of its connection with the perineum (urethra and anus). In further support of this is the escape of this group of nerve cells in case 1 (Fig. 1, S. 3 and S. 4), where in S. 3 the whole of the postero-lateral and post-postero-lateral groups were degenerated.

The examination of these two cases has established the centre for the psoas-iliacus and pectineus, the obturator internus, pyriformis and gemelli; the muscles of the leg and foot; and lastly, for the muscles supplied by the internal pudic nerve.

With regard to the localisation of the other lumbo-sacral centres, much information may be gained by contrasting the results just described with those obtained by Van Gehuchten, Nelis, De Buck, Sano, etc.

As already stated, the intrinsic muscles of the foot have their centres in the post-postero-lateral groups of the first, second, and third sacral segments, especially in the second. The centres for calf and extrinsic foot muscles occupy the whole of that part of the postero-lateral group which lies below the fourth lumbar segment, namely, in L. 5, S. 1, S. 2, and upper part of S. 3. The remaining muscles of the lower extremity must have their centres in the remaining groups of cells of the lumbo-sacral region, namely, in the postero-lateral group above the fifth lumbar (considered by Van Gehuchten to be part of the antero-lateral group), the antero-lateral and central groups.

A case of Van Gehuchten's of amputation of the thigh throws much light on the distribution of the centres, especially when considered along with the known origin of the lumbo-sacral plexus. He found in addition to the changes in the post-postero-lateral, and postero-lateral groups, which were manifestly due to the removal of the leg and foot, that Nissl's reaction was present in the central group in L. 5, S. 1 and S. 2, and in his antero-lateral group (which includes my postero-lateral group) in L. 2, L. 3, and L. 4; and that, on the other hand, the upper central group in L. 2, L. 3, and L. 4, and the lower antero-lateral in L. 5, S. 1, and S. 2, were intact. I have endeavoured to indicate the positions of the degenerated and the normal groups of cells in Fig. 4, D.

These affected groups of cells, which show Nissl's reaction, must obviously form the nuclei of origin of the muscles of the thigh, which have been removed by the operation, namely, the hamstrings, the extensors of the knee, the adductors and sartorius. The hamstrings, as we know, are innervated by the great sciatic nerve, which again is formed by roots derived from L. 5, S. 1, S. 2 and S. 3. These, with the exception of the last, are the very segments in which the central group of cells shows the Nissl reaction. The inference seems obvious that this part of the central group must contain the nuclei of origin of the hamstring muscles.

The remaining muscles, namely, the adductors, quadriceps, sartorius, and tensor fasciæ femoris, must, if the above reasoning hold good, arise from the upper part of the antero-lateral group (using the term in Van Gehuchten's sense).

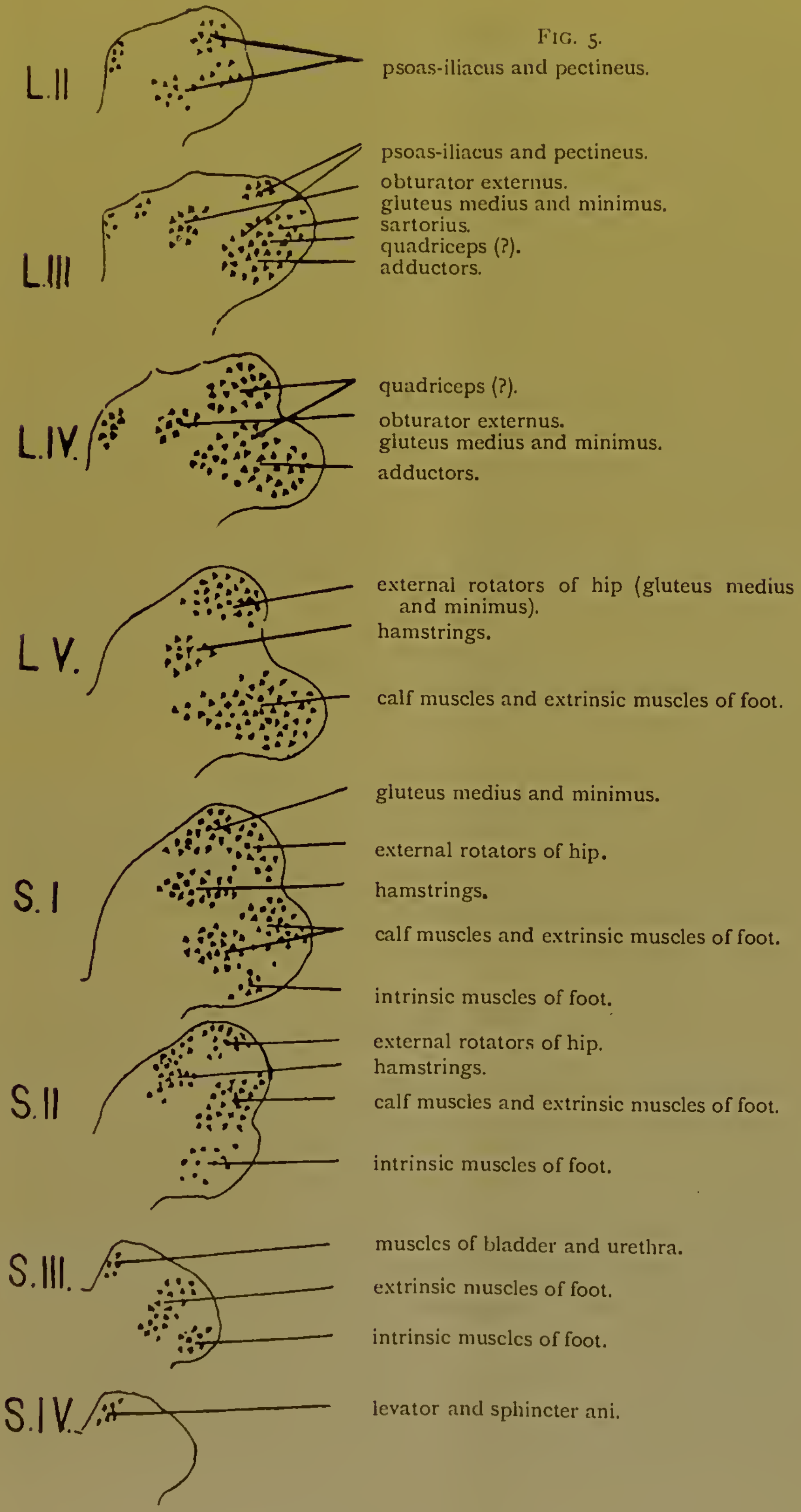
There is no direct evidence as yet to show whether the quadriceps lies in front of, or behind, the adductor group, although the remarkable leash of sensory fibres which passes at the level of L. 3 and L. 4, directly forwards towards the antero-lateral group of cells, and which is supposed, with much reason, to be part of the nervous arc involved in the knee-jerk, would seem to indicate that this antero-lateral group was the centre for the quadriceps. In this case the adductor centre would lie in the postero-lateral group. But for the determination of these points further evidence must be obtained.

If we turn now to the muscles which have not been removed, and to the centres which have been left intact, we find that the former consist of the psoas-iliacus and pectineus, the external rotators of the hips, namely the gluteus maximus, obturator internus, gemelli, pyriformis, and quadratus femoris, in addition to the gluteus medius and minimus and the obturator externus.

My positive conclusions with regard to the psoas-iliacus, supported by the anatomical evidence as to its roots, show that its centres must lie in the second and third lumbar segments in the antero-lateral and postero-lateral groups of cells, and that consequently the view of Van Gehuchten, which places them in the lower antero-lateral column from L. 3 to S. 5, with which segments their nerve-roots are in no way connected, is erroneous. My second case has also proved that the centres for the obturator internus, pyriformis, and probably gemelli, are situated in the anterior portion of the antero-lateral group in S. 1 and S. 2, a fact which is in direct harmony with the established origin of their nerve roots. It may be considered as reasonably probable therefore that the gluteus maximus also, which is itself an external rotator and which derives the main portion of its roots from L. 5, S. 1 and S. 2 has its centre in the remaining portion of the antero-lateral group at these levels. In my case, the gluteus maximus was certainly removed, and this portion of the nucleus had undergone the Nissl's reaction. In Van Gehuchten's case, the gluteus maximus was certainly spared as well as the whole of the external rotators. In it the whole of the lower antero-lateral groups was intact. The upper central group including L. 2, L. 3 and L. 4 remains therefore for the gluteus medius and minimus and obturator externus. With regard to the last mentioned, the obturator externus, this localisation is in exact conformity with the known origin of its roots. With regard to the two remaining glutei, however, the roots assigned to these are stated to arise from L. 4, L. 5 and S. 1, which, if correct, would require their centres to be placed rather in the lower antero-lateral than in the upper central group.

Turning now to the mesial group of cells in the third and fourth sacral segments, we found that it was partly, but not entirely, degenerated. The degeneration was evidently related to the interference with the pudic nerve, and is an indication that the centres for the striped muscles which this nerve supplies

FIG. 5.


L.II
psoas-iliacus and pectineus.
L.III
psoas-iliacus and pectineus.
obturator externus.
gluteus medius and minimus.
sartorius.
quadriceps (?).
adductors.
L.IV.
quadriceps (?).
obturator externus.
gluteus medius and minimus.
adductors.
L.V.
external rotators of hip (gluteus medius and minimus).
hamstrings.
calf muscles and extrinsic muscles of foot.
S.I
gluteus medius and minimus.
external rotators of hip.
hamstrings.
calf muscles and extrinsic muscles of foot.
intrinsic muscles of foot.
S.II
external rotators of hip.
hamstrings.
calf muscles and extrinsic muscles of foot.
intrinsic muscles of foot.
S.III.
muscles of bladder and urethra.
extrinsic muscles of foot.
intrinsic muscles of foot.
S.IV.
levator and sphincter ani.

are situated in this group of cells. The escape of some of the cells may be due to the fact that the posterior parts of the levator and sphincter ani are supplied by nerves arising from the fourth sacral segment independently of the pudic nerve; but I am not in a position to state definitely that the pudic nerve was entirely destroyed in the operation, and therefore cannot affirm that the normal condition of these mesial cells may not have been due to the escape of some of the fibres of the pudic nerve.

Van Gehuchten has placed the centres for the perinæum in the mesial group (its antero-external division) in L. 3 and L. 4, and that for the levator ani in the upper central group opposite the third and fourth lumbar; a view which is not supported anatomically otherwise, and is based upon what I believe to be the erroneous view of Kaiser and Sano, that the mesial group is destined only for the supply of muscles in relation to the neural tube.

It ought also to be mentioned that not a single degenerated cell was found on the opposite half of the affected cord, every section having been carefully scrutinised to determine this point.

In the accompanying diagram (Fig. 5), I have endeavoured to show the relation of the various centres to the muscles of the lower extremity, in so far as has been definitely ascertained or may reasonably be considered probable. In several respects it must be admitted that the confirmation of future observations is still required.

In comparing this localisation with that obtained by Ferrier on experimental grounds, and by Thorburn and Kocher from the examination and comparison of clinical cases, it will be seen that the correspondence of my results with those of Ferrier is remarkably close, the only essential difference being that Ferrier finds no motor centre in the third sacral segment, and in the second one only, for the intrinsic muscles of the foot; while my scheme, which is in agreement with most of Van Gehuchten's results, shows centres for the leg and foot in the third sacral as well as in the second, in the latter of which there appears to be also a centre for the hamstrings. A table showing the various schemes referred to is appended for the sake of comparison.

	Kocher	Thorburn	Ferrier	Bruce
L. I.	—	—	—	—
II.	—	—	—	Psoas-iliacus
III.	Psoas-iliacus (pectineus) Sartorius Adductors — —	Psoas-iliacus Sartorius Adductors — —	Psoas-iliacus Sartorius Adductors Extensor cruris —	Psoas-iliacus Sartorius Adductors Extensor cruris Obturator externus
IV.	Extensor cruris (Gracilis) — Glut. med. and min. (Tens. fasc. fem.) Obt. ext. ? — —	Extensor cruris — Abductors of thigh — Extensors of hip —	Extensor cruris Adductors — — — Peroneus longus	Extensor cruris Adductors Glut. med. and min. — — —
V.	Hamstrings — — Tensor fasc. fem. Glut. med. and min.	Hamstrings — — — —	Hamstrings External rotators of hip Leg muscles Long flexors and extensors of toes Peronei —	Hamstrings External rotators of hip Calf muscles Extrinsic foot muscles — —
S. I.	— — — Long extensors of foot and toes Peronei brev. and long. External rotators of hip (pyriformis) Glut. max.	— — Calf muscles Peronei — — —	Hamstrings — Calf muscles Flex. long hallucis — Intrinsic foot muscles — —	Hamstrings External rotators of hip Calf muscles Extrinsic foot muscles — Intrinsic foot muscles — —
II.	— — Calf muscles Long flexors of foot and toes Intrinsic muscles of foot	— — Extensors of ankle — Intrinsic muscles of foot	— — — — Intrinsic muscles of foot	Hamstrings External rotators of hip Calf muscles Extrinsic muscles of foot Intrinsic muscles of foot
III.	— —	— —	— —	Calf muscles Extrinsic muscles of foot Intrinsic muscles of foot
IV.	—	—	—	—
V.	—	—	—	—

REFERENCES.

Onuf, *Journal of Nervous and Mental Disease*, August 1899.

Sano, "Les localisations motrices dans la moelle épinière." *Journal de Neurologie*, 1897, p. 254.

Van Gehuchten and de Buck, "La chromatolyse dans les cornes anterieures de la moelle après désarticulation de la jambe." *Journal de Neurologie*, 1898.

Van Gehuchten and Nelis, *Journal de Neurologie*, 1899.

Van Gehuchten and de Neef, *Le Nevraxe*, vol. i. fasc. 2.

Ferrier, "Brain," vol. iv., 1882.

Thorburn, "Contribution to the Surgery of the Spinal Cord," 1889.

Kocher, "Mittheilungen über die Grenzgebiete der Medizin und Chirurgie," 1896.